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ENVIRONMENTAL MANAGEMENT AND DECISION SUPPORT SYSTEM

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ABSTRACT: Environmental information is available to managers through a broad range of methods and tools, from raw data provision to knowledge-based decision support systems. The design of 'environmental information systems' (EIS) to enhance the use of environmental information includes consideration of data formats, user interface, the nature of management questions, data characteristics such as variability, reliability and periodicity, and the management culture within which the EIS is intended for use. Current approaches in building environmental decision support systems (EDSS) for environmental problems, tend to adopt a "systemic" approach. This kind of approach analyzes a problem in terms of all the knowledge, the data and the responsibilities it depends on. So, the proposed methodologies aim to be integrated in larger information systems by exploiting the fact that different stakeholders may manage information sources and resources that are relevant to problem solutions. This paper focuses on the requirement analysis and the design of a prototype software system devoted to support decision making by the stakeholders of the environmental advisory service.

Keywords: Environmental information systems; Software design; Integrated environmental management; Multicriteria Analysis

1. INTRODUCTION

Current approaches in building environmental decision support systems (EDSS) for environmental problems, tend to adopt a "systemic" approach. This kind of approach analyzes a problem in terms of all the knowledge, the data and the responsibilities it depends on. So, the proposed methodologies aim to be integrated in larger information systems by exploiting the fact that different stakeholders may manage information sources and resources that are relevant to problem solutions. This paper focuses on the requirement analysis and the design of a software system devoted to support decision making by the stakeholders of the environmental advisory service.

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Environmental information is available to managers through a broad range of methods and tools, from raw data provision to knowledge-based decision support systems. The design of 'environmental information systems' (EIS) to enhance the use of environmental information includes consideration of data formats, user interface, the nature of management questions, data characteristics such as variability, reliability and periodicity, and the management culture within which the EIS is intended for use. One of the principles of EIS design is that the designer must know potential users, their wishes, needs, likes and dislikes. Interface prototyping is an approach to EIS design that provides designers with useful information about users and their interaction with the EIS under construction.

The assessment of Environmental Impact can be achieved with a large variety of available tools for generating and processing Environmental information. This kind of information can be used for supporting decisions about policy strategic plans, implementation etc. Some of the tools used for Environmental system analysis are: Environmental Impact Assessment (EIA), System of Economic and Environmental Accounting (SEEA), Environmental Auditing, Life Cycle Assessment (LCA) and Material Flow Analysis (MFA) (Finnvedem et al., 2004). These methods examine the environmental impacts from different views and characteristics.

A systematic method for addressing environmental consequences is needed to answer the additional community and environmental concerns. One method of managing environmental impacts has been put down into a series of rules (protocols) as an Environmental Management System (EMS). This method is a promising information – rich and inclusive framework for addressing environmental issues.

2. ENVIRONMENTAL ISSUES

Most of the environmental problems are characterized by two main features. First there is the environmental processes and resources which are often irreversible courses of action (e.g. consumption, conversion, exploitation and degradation can be a one – way decision, therefore an appropriate model is required). Second the incomplete knowledge leads to uncertainty (e.g. natural processes and effects of our actions on those processes) calling for particular attention in choosing the modeling techniques to be deployed. Decision making in environmental applications can be profitably enhanced by using quantitative methods capable of capturing the inherent uncertainty and accounting for both economic and social environmental aspects of the problems. However the quantification of environmental parameters and variables of interest can be a non trivial process. As an example we can consider the public goods (water, air, landscape etc) that are not exchanged in the market because their value may only partially or not at all reflected in a price.

Environmental planning seeks to improve and protect environmental quality for residents both through segregating activities that are environmentally incompatible.

For an effective environmental planning an interaction (and possible overlay) among three components is required. Namely

1. the land use and Urban structure
2. the social systems regulation and laws and
3. the environmental awareness and ethics

The first consists of sets of the infrastructure of the city (buildings, railways, roads, ports, etc). The second consists of sets of rules and regulations (laws and legislation), ordinances including habits, ethics and traditionally established codes of conduct. The third is a blend of needs, education, learning which leads to the development of environmental consciousness. The participation in planning through collaboration of citizens, enterprises and administration will determine the process of interaction with the surrounding environment. The basic methods used for the formulation of the basic environmental planning problems are: the multicriteria optimization methods, the optimal control methods and the methods based on stochastic programming.

2.1 Characteristics of Environmental Information

Environmental Information has several attributes which make its formal representation different from that of other information (e.g. business or industrial systems). Some of them are described in (Guariso & Werthner, 1989) and (Rizzoli &Young, 1997), such as:

- Time: Some environmental processes are treated as continuous events with time being a continuous variable. However some processes are better viewed as discrete event models.
- Locally coverage: The physical processes that take place in an environmental system are expressed in a two or three dimensional space. Sts of ordinary or partial differential equations describe these processes with two or three dimensional spatial vectors as variables. Data are usually ill – organized and proprietary of regional agencies. They are stored in spatial databases often within a GIS to assist in data analysis.
- Complex trade offs: environmental systems are complex usually involving interactions between many disciplines (i.e. physicochemical and biological). Models of such systems require complex trade offs among private and social goals and multidisciplinary expertise. Therefore they need critical value judgments and different research fields to find a common ground to communicate.
- Uncertainty: Many environmental processes are stochastic. The parameters of models representing such processes are usually uncertain and we know their ranges approximately. In addition we deal with conflicting information which calls for statistical analysis and qualitative analysis of model equations.
- Value oriented: Many environmental processes are value oriented and periodic in time. These attributes increase the complexity of the parameter calibration and validation as well as the data storage. In addition the following important features are also identified:

- Heterogeneity and scale: Even though environmental data attributes (i.e. water or forest) may have the same name and units (i.e. forest area in hectares, tree basal area in cm^2 and tree volume in m^3), what is being defined and measured in each European country radically differs from what is being defined and measured in many other European countries. Although an environmental DBMS might have a great deal of interoperability (in terms of universal ability to access), comparisons between the forest information of different European countries, using various tools (tabulation or pictures) would be meaningless since the data are incommensurate. Many of the variations in definitions depend on latitude and the different nature of the environmental data found in the North and the South of Europe. Given that the definitions and measures of environmental variables depend largely on fragmentation measures, it should be imperative to develop a model which recalibrates the stated environmental variables in any particular region by using the local models. If such models of standardization of definitions and measurements were built, it would be possible to put them together into a tool – kit of such models, possibly as a web – service. This web – service could then be used to compare environmental inventory data from different regions or countries on a common standardized basis.
- Lack of information: observational data on environmental systems, particularly on regional level, are typically only sufficient for the development of simple local models.

3. THE UNCERTAINTY OF ENVIRONMENTAL INFORMATION AS A FACTOR OF LIMITING THE EFFECTIVENESS OF ENVIRONMENTAL MANAGEMENT SYSTEM

Recent applications in environmental systems have necessitated the integration of data from multiple, heterogeneous sources. The integration process involves challenges related to issues of uncertainty and imprecision associated with both the data and the process itself. While the handling of uncertainty in geographical information systems (GIS) has been a focal point of research in recent years, the additional challenges of dealing with multiple data sources and types, as well as specific fields of analysis, lead to much more complex situations.

Uncertainty of environmental information is often represented by chance constraints, which retains a Linear Programming structure under assumptions of independence. With joint chance constraints the assumptions are such that a certainty equivalent is represented by a quadratic constraint, which is sometimes presumed as convex. Other models that deal with uncertainty also introduce non - linearity by seeking a minimum variance and/or violation penalty. The uncertainty, deriving from incomplete knowledge, concerning natural processes and the effects of our actions on those processes, call for a particular attention in choosing the modeling techniques to be deployed. The theoretical framework for decision making in environmental applications in the presence of uncertainty is the quasi – optional value approach (Arrow & Fischer, 1974; Henry, 1974; Conrad, 1980; Hanemann, 1989; Coggins & Ramezani, 1998; EEA, 2002).

Data gathering is the first level of a EDSS encompasses the task involved in data gathering and registration into databases. Original raw data are often defective, requiring a number of pre – processing procedures, before they can be registered in an understandable and interpretable way. Missing data as well as uncertainty must also be considered in this level.

One of the major uncertainties in Environmental Management Decision Support System is the climate sensibility (Webster & Sokolov, 2000), which refers to the equilibrium response of the climate system to a given forcing. Another important uncertainty that accounts for different results from transient simulations is the rate of heat uptake by the deep ocean. Most of the uncertainty studies performed so far are in fact sensitivity studies, in which the sensitivity of the model projections to different parameters is explored by repeating a numerical simulation with the parameter in question set to a nominal (a low and a high) value while the rest of the parameters are fixed. Sensitivity analysis usually gives only ranges of possible outcomes. The goal of uncertainty analysis is to obtain more detailed information about climate responses, including the mean, standard deviation, ranges with attached confidence (e.g. 95% interval) and probability of exceeding some threshold level.

4. MCDA AND DPSIR FRAMEWORK

Environmental planning and decision-making contain usually conflicting aspects and are characterized by environmental, social, political, economic and cultural value judgements. Several alternatives have to be compared and evaluated using many different criteria and resulting in a large quantity of data which are often uncertain or inaccurate. The decision makers (DM) often have conflicting preferences complicating the process further and the different stakeholders with various points of view should also be taken into account. Therefore, a single, objectively best solution does not generally exist, and the planning process can be seen as a search for acceptable compromise solutions.

Decision problems concerning environmental and natural resources management are usually complex or even hyper-complex problems (Brans, 2002) A deep analysis and decision making process require a high background in environmental, economic and social disciplines The paradox here is that the scientific community is mostly working on very detailed and more narrow aspects whereas the managers require a holistic and ecosystemic approach, not necessarily at a high level of detail (Elliot, 2002). But the gap between those who analyse and those who decide, is not only in the knowledge but also in the aims and the way of thinking (Vázquez & Mattei, 2003). For that reason, our objective proposing the present methodology is to link politic and science world providing a tool to facilitate the communication between them.

Different multi-criteria decision analysis (MCDA) methods have been developed to support complex planning and decision processes to provide a framework for collecting, storing and processing the relevant information (Bana e Costa, 1986). The core of a multi-criteria decision aid method is a decision model, which is a formal specification of how different kinds of information are combined together to reach a solution. MCDA methods are used in environmental planning and decision-making processes in order to clarify the planning process, to avoid various distortions, and to manage all the information, criteria and uncertainties. MCDA methods can alleviate the problems caused by limited human computational power. Intuitive or adaptive choices are replaced by a justified and jointly accepted model. (Lahdelma et al., 2000).

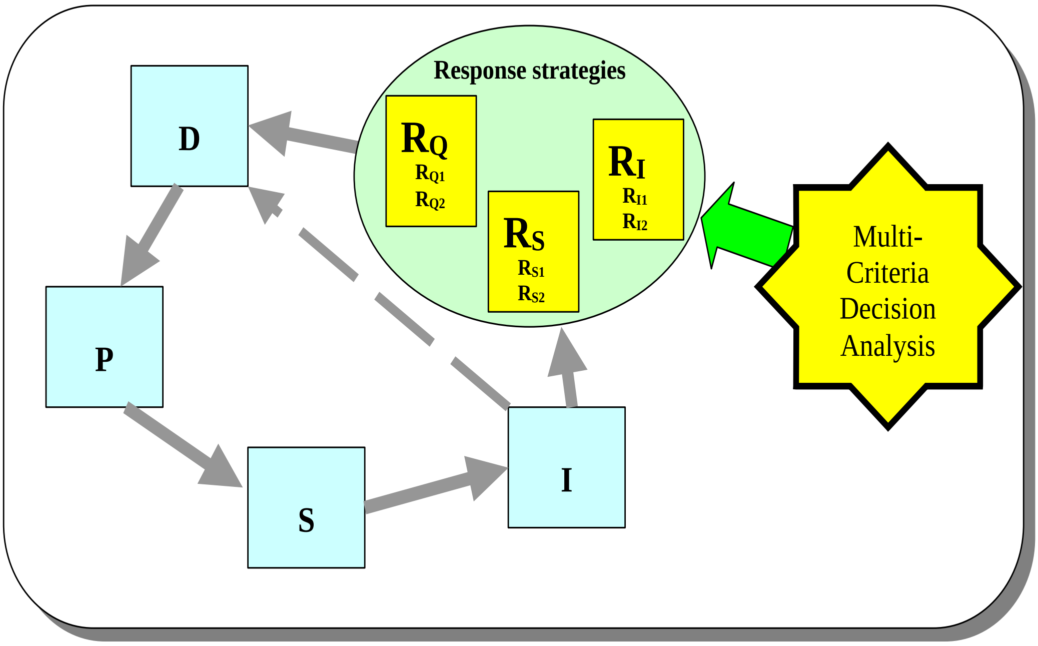

Fig. 1

The stakeholders consist of all the people who are associated with the planning and decision process or who are affected by the decision. They can be classified into standard stakeholders and interest groups. Standard stakeholders are those who have the legitimate responsibility to participate in the process. They include the decision makers (DMs), experts, and planners and analysts responsible for the preparations and managing the process. Interest groups are typically political parties, civic organisations and residents of the impact area.

The decision making process usually consists of following phases: (i) define alternatives and criteria, (ii) make measurements, (iii) choose decision aid, (iv) provide preference information, (v) form draft solutions and (vi) make final decision. All the stakeholders should participate in the definition of alternatives and criteria. Measurements are usually carried out by experts and planners. A multiple criteria decision problem consists of a finite set of alternatives that are evaluated in terms of multiple criteria. The criteria provide numerical measures for the relevant impacts of different alternatives. The relevance of different impacts depends on the process and how different stakeholders are able to express their views. For the transparency of the process it is important to define precisely how each criterion is formulated and measured. Usually criteria are aggregate values computed from much larger amount of so-called primary factors.

The impacts can be classified according to their temporal, spatial and regulatory properties. Temporally, impacts can be classified as unique, recurrent or continuous and can be either short or long term. Spatially, impacts can be classified as local, regional, national, international or global. Impacts can be formally regulated or not regulated at all. (Lahdelma et al., 2000.) The definition of the relevance of different impacts depends on the stakeholders' points of view and their position in the definition process. The various techniques for determining the relevance can be classified as the bottom-up and the hierarchical top-down approach. e.g. (Saaty, 2000) uses the hierarchical approach in his AHP (Analytical Hierarchy Process) process, while Lahdelma (Lahdelma et al., (2000) use the bottom-up approach in their SMAA (Stochastic Multicriteria Acceptability Analysis) method.

The defined criteria should meet the following requirements (Keeney & Raiffa, 1976):

1. Completeness: all the important points of view of the problem are covered.
2. Operationality: the set of criteria can be measured and used meaningfully in the analysis.
3. Nonredundancy: two or more criteria should not measure the same thing.
4. Minimality: the dimension of the problem should be kept to a minimum.

There are some requirements for the multi-criteria decision analysis method to be used in public environmental problems (Lahdelma et al., 2000):

1. The method should be well defined and easy to understand, particularly regarding its central elements, such as modelling criteria and definition of weights.
2. The technique must be able to support the necessary number of decision makers.
3. The method must be able to manage the necessary number of alternatives and criteria.
4. The method should be able to handle the inaccurate or uncertain criteria information.
5. Due to time and money constraints, the need of preference information from the decision makers should be as small as possible.

Several different multi-criteria methods have been applied to environmental problems. The main approaches can be classified based on the type of decision model they apply (Lahdelma et al., 2000):

1. *Value or utility function based methods*, such as multiattribute utility theory (MAUT) (Keeney and Raiffa, 1976), SMART, the analytical hierarchy process (AHP (Saaty, 1980), interval AHP (Salo & Hämäläinen, 1992), and the stochastic multicriteria acceptability analysis methods SMAA (Lahdelma et al., 1998), SMAA-2 (Lahdelma & Salminen, 2000, Hokkanen et al., 1998b), SMAA-D (Lahdelma et al., 1999), and SMAA-O (Miettinen et al 1999).
2. *Outranking methods* such as Electre II (Roy and Bertier 1971), Electre III (Roy, 1978), Electre IV (Roy & Hugonnard, 1982), Promethe I and II methods (Brans & Vincke, 1985), and SMAA-3 (Hokkanen et al., 1998a).

Another classification can be made based on the use of preference information in the method. Most of the methods require preference information in the form of precise weights. Methods that do not require decision makers' preference information are acceptability analysis (Bana e Costa, 1986; Bana e Costa, 1988), SMAA methods, data envelopment analysis (DEA) (Charnes et al., 1978), and Electre IV.

Therefore MCDA method can be combined in the DPSIR framework. In this framework the alternatives consist of the different response strategies (Fig. 3). The response strategies can be divided into three categories: Activity responses R_Q, Intensity R_I, and Structural R_S. Each one of these categories comprises several responses

5. THE SYSTEMS' ARCHITECTURE

A DSS is a computer system that assists decision – makers in choosing between alternative scenarios (Fox & Das, 2000). It incorporates an explicit decision procedure based on a set of theoretical principles that justify the "rationality" of this procedure. Those systems are built by integrating several formal system methods as artificial intelligence methods, gis components, data mining techniques, mathematical and statistical techniques and environmental issues (Fig. 1).

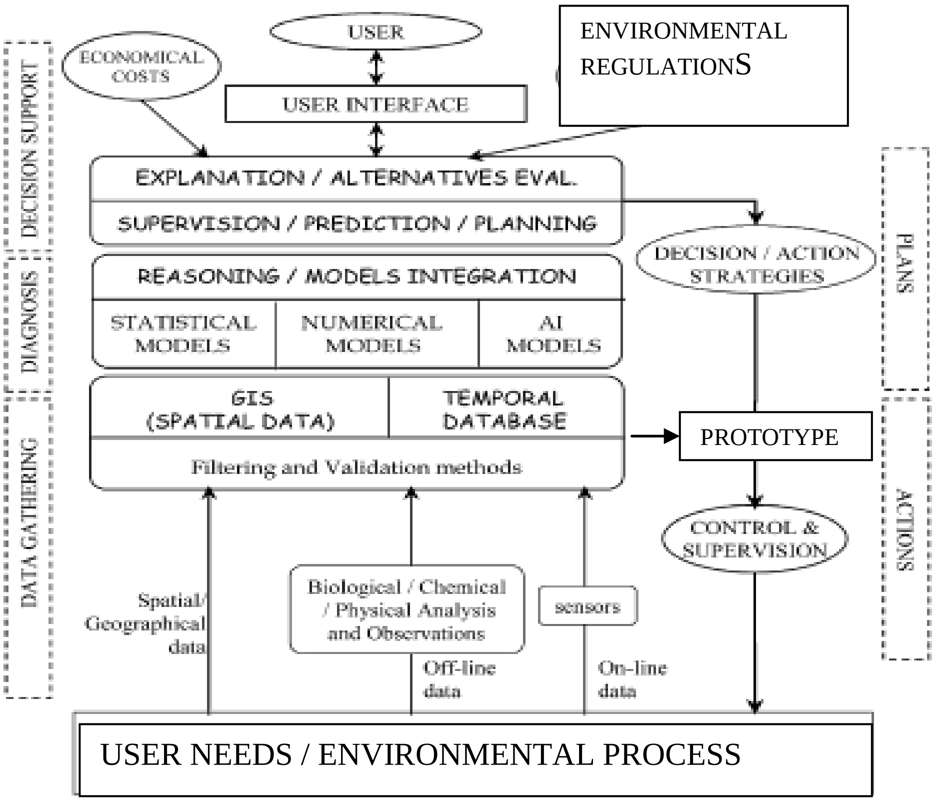

Fig. 2

The methodology used is shown schematically in Fig. 3 and it is related to the ECOSTAT system (Papaioannou & Tassopoulos, 2004).

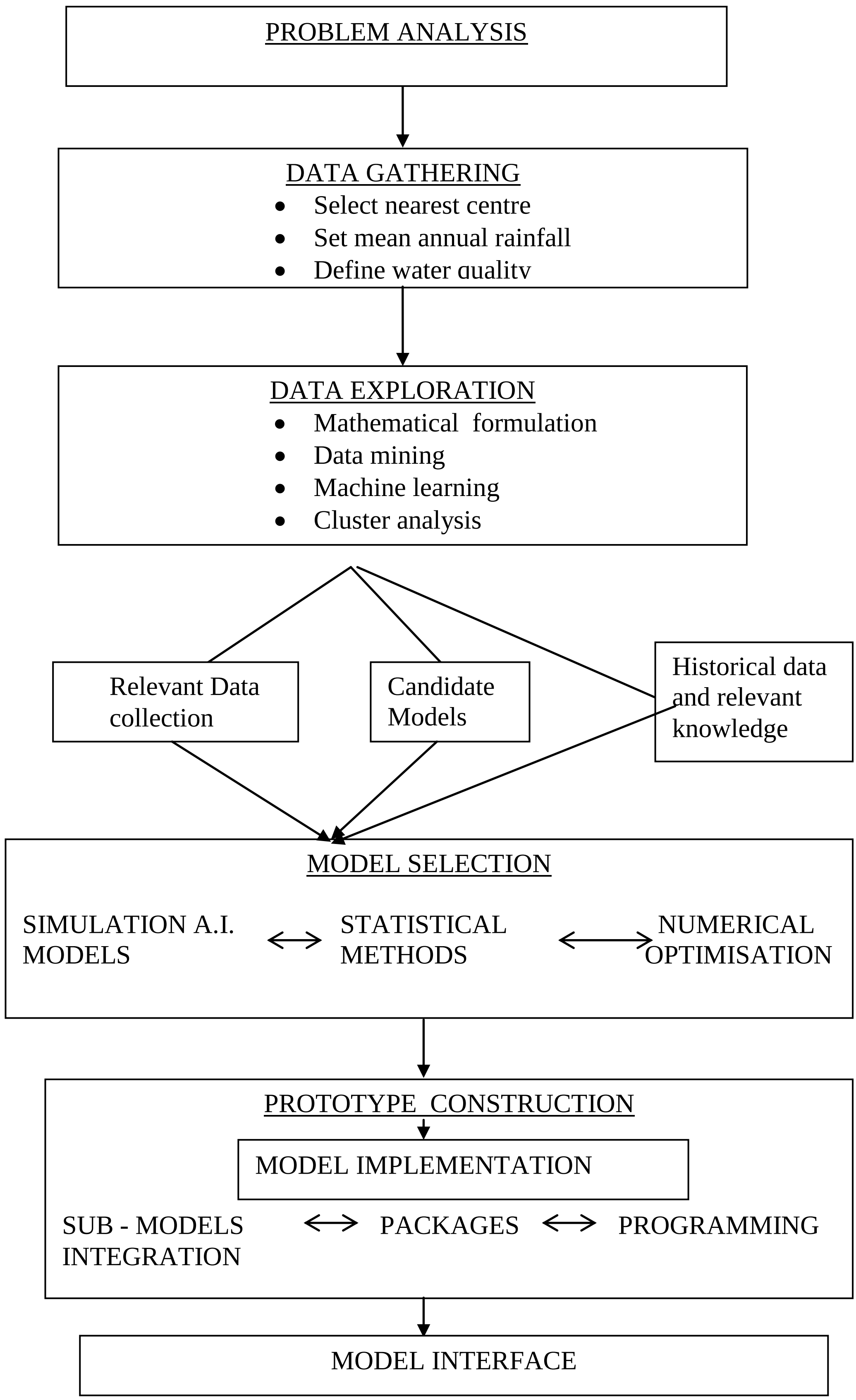
PROBLEM ANALYSIS
DATA GATHERING
Select nearest centre
Set mean annual rainfall
Define water quality
DATA EXPLORATION
Mathematical formulation
Data mining
Machine learning
Cluster analysis
Relevant Data collection
Candidate Models
Historical data and relevant knowledge
MODEL SELECTION
SIMULATION A.I. MODELS
STATISTICAL METHODS
NUMERICAL OPTIMISATION
PROTOTYPE CONSTRUCTION
MODEL IMPLEMENTATION
SUB - MODELS INTEGRATION
PACKAGES
PROGRAMMING
MODEL INTERFACE

Fig. 3 DSSE

People from different backgrounds and fields of interest view quite differently what environmental information systems and environmental decision support systems are and what their frameworks and components should be. However, by having a modular framework such as the one above mentioned, the components required for a particular application can be easily added or modified. By providing the system user with a simple development language and libraries of special development functions, the system can easily be modified to fit a wide range of applications. Interfaces can be created to allow as much simplification of the system as required for the end user.

6. DISCUSSION

This paper described the requirement analysis and the design of a decision support system, for the environmental advisory service in the framework of the DPSIR using a software engineering methodology that allows to model the domain stakeholders goal and mutual dependencies explicitly with the aid of the MCDA technique. We discussed the early requirement and late requirement analyses specifying the reasons for dependencies between social and system actors. We observed that the complex environmental planning and analysis requirements for such systems today involve collection and integration of geographical data from multiple, diverse sources.

User do not know or cannot express, what they want and need. Therefore we provide an initial system (prototype) to react and improve upon. The prototype will run the application, highlight the data, calculation, user inputs and options that were likely to be associated with each screen interface. We do not include algorithms or models in the program, but the users and developers were able to see whether their knowledge and data would fit into the program under construction. Further more the developers and potential users started to get down to the detail of how the program might work. In this case the emphasis shifted from the technical issues of what the program might look like and how it would operate to the essential ones of specification of the environmental quality of the environmental quality model, collection and collation of the relevant data and clear formulation of the output. The problems being faced in development is not essentially ones of lack of knowledge or even the capacity to access relevant data, but rather ones of the transformation of data into information relevant to managers.

The initial prototype, containing no algorithms or mathematical models, provided potential users and technical developers with an empty shell within which they identified how their particular data and information would be incorporated. This “empty” shell enabled those without modelling expertise to see that a useable tool was indeed possible. It was able to provide a vehicle by which the users and developers could move on to the problem-solving process itself, and provided the flexibility for users to ensure good interface design by iterative testing. After exposure to the first prototype, the development team were happy to turn to matters of data and model detail, and to return to interface design at various times throughout development of the EIS.

The realization of a fully functional environmental information system for public use as supplement for an existing DSS is underway. This EIS will present complex specialized scientific and technical information in a form that is comprehensible for diverse interest groups and will allow the transfer information between groups. In the next step we will test a web-board with experts as moderators; furthermore powerful search tools need to be implemented to make information in our long reports readily available to the users, and we need to find ways to organize and filter information according to topic categories.

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